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## THE USE OF KNOWLEDGE BASED SYSTEMS TECHNIQUES IN ESM PROCESSING

by

J.H.Palfreyman  
Business Development Manager — Electronic Warfare  
Software Sciences Ltd  
Farnborough, Hampshire GU14 7NB  
UK

### SUMMARY

The Electronic Support Measures (ESM) System attempts to detect, analyse and classify sources of radio and radar emissions in the environment. The ESM system provides valuable emitter classification information to the host platform's Command and Control System or associated Electronic Countermeasures (ECM) equipment. However, the current generation of Automatic ESM systems often produce ambiguous or incorrect emitter classifications in the adverse conditions of actual conflict. This paper describes the application of Knowledge Based Systems techniques to ESM processing and outlines the development and evaluation of a Knowledge Based ESM system model aimed specifically at improving the emitter classification capability of automatic ESM.

1	<u>GLOSSARY OF TERMS</u>
C <sup>2</sup>	Command and Control
CEF	Current Emitter File
CW	Continuous Wave
DF	Direction Finding
ECM	Electronic Countermeasures
ESM	Electronic Support Measures
EW	Electronic Warfare
EWBG	Electronic Warfare Scenario Generator
EWRM	Electronic Warfare Receiver Model
GHz	Giga-Hertz (10 <sup>9</sup> Hz)
KB-ESM	Knowledge Based Electronic Support Measures
KBS	Knowledge Based System
KS	Knowledge Source
PRI	Pulse Repetition Interval
PW	Pulse Width
RF	Radio Frequency
TOA	Time of Arrival

## 2 ELECTRONIC SUPPORT MEASURES

2.1 The Electronic Support Measures (ESM) system is concerned with the detection, analysis and classification of radio and radar signals. ESM provides details of the signal environment either to the host platform's Command and Control System, for use in tactical situation assessment or to an integrated Electronic Countermeasures (ECM) system. This paper will be restricted to the discussion of Radar ESM, although the techniques described in subsequent sections will be generally applicable to radio frequency ESM systems.

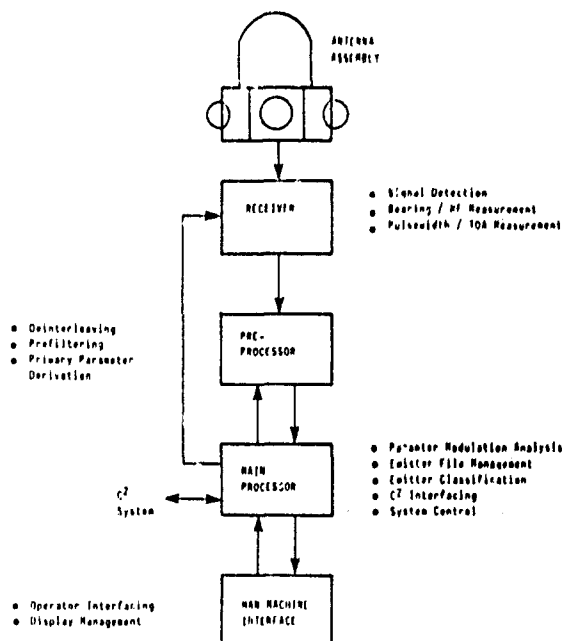


FIGURE 1 ESM SYSTEM BLOCK DIAGRAM

2.2 The block diagram of a typical Automatic ESM System is presented in Figure 1. The system is composed of the following subsystems.

- the Antenna and Receiver
- the Preprocessor
- the Main Processor
- the Man-Machine Interface

2.3 The Antenna and Receiver must be capable of detection of all radar frequencies used by own forces, neutral and enemy radar sets. The typical frequency coverage is 2-18 GHz although extensions to cover the millimetric wavelengths above 18 GHz are becoming of increased importance. Similarly the sub-system must be able to detect signals arriving at all azimuth angles around the host platform. The receiving unit detects incident signals (above system sensitivity) and measures the signal characteristics. The characteristics of a typical pulsed radar signal that are measured by the receiver are:

- Angle of Arrival (bearing)
- Carrier Frequency
- Pulse Width
- Amplitude
- Time of Arrival

2.4 However, since the receiver will detect and measure each incident pulse in chronological order, the receiver output will require sorting to reconstruct pulse chains from the individual emitters in the environment. This sorting process is carried out by the Pre-processing element of the system, and is termed 'De-interleaving'. The aim of the de-interleaving function is to produce just one pulse chain for each detectable emitter in the environment, although this is seldom possible in practice.

2.5 The Pre-processor element also acts as a data rate reduction mechanism to ensure that the main processor can cope with its pulse chain analysis, classification and system control tasks. In addition, the Pre-processor removes all unwanted pulse data (e.g. from high duty rate emitters) that had previously been analysed and classified by the system to further reduce the mainprocessor load.

2.6 Each pulse chain derived by the de-interleaver is either associated with a current entry, or creates a new entry in the Current Emitter File (CEF). Subsequent analysis of the interpulse modulation of the RF, PRI, PW and Scan parameters are stored against this CEF entry.

2.7 The CEF maintenance algorithms attempt to solve the problems created by the de-interleaver and in particular the reconstruction process is based largely upon parameter matching techniques - that is pulse chains are combined with existing CEF entries if their parameters meet some form of matching criteria.

2.8 The Modulation Analysis Functions within Automatic ESM attempt to augment the basic pulse chain

Parameters produced by the de-interleaver (i.e. bearing, RF range etc.) with details of how the pulse parameters vary over the detected pulse chain. The Radio Frequency, Pulse Repetition Interval and Pulse width parameters are often analysed by the compilation of parameter occurrence histograms. These are subsequently interpreted to give the modulation details of the particular parameter.

2.9 The amplitude modulation of a pulse chain can be analysed to produce an indication of the periodicity and antenna scan pattern of the target radar. This information yields important extra information for use in the classification process, and the function is termed Scan Analysis.

2.10 The emitter classification function is accomplished by comparing the parameters of a particular CEF entry with each record in a library of known emitter characteristics. This library contains parametric details of all radar emitters within the system's frequency coverage that are likely to be encountered in a particular operational situation.

2.11 The library comparison process results in a candidate set of emitter records from the library which match the CEF entry. This candidate set is then subjected to confidence assessment which produces a measure of the accuracy with which the CEF entry parameters match those of the library entry. This confidence indicates the likelihood of each candidate emitter type corresponding to the particular CEF entry.

2.12 ESM systems can be used in a variety of different roles in a conflict situation, including:

- a) SELF PROTECTION - in association with 'hard kill' (e.g. ship to ship missile systems) or 'soft kill' (e.g. Electronic Countermeasures) systems, the ESM equipment can help protect the host platform against radar-assisted attack.
- b) TACTICAL SITUATION ASSESSMENT - since the ESM system provides emitter classification data, it is obviously complementary to primary radar (which measures range and bearing of targets) in the assessment of the host platform's tactical environment.
- c) EARLY WARNING - it is often possible to detect targets at long range from the host platform using ESM, even outside the primary radar's coverage. It is also possible in certain situations to detect, analyse and classify radars over the conditions by exploiting Anomalous Propagation (ANAPROP) conditions.

It is therefore obvious that ESM must be capable of deriving high quality emitter classifications to fulfill these important roles and to be fully effective.

2.13 However, Automatic ESM systems are required to operate in a number of adverse conditions which makes the successful classification of emitters difficult. These adverse conditions include.

- the very high pulse data rates that may be detected by a sensitive ESM system in postulated conflict scenarios.
- the trend towards usage of radars exhibiting complex modulation strategies, which make the ESM systems deinterleaving and analysis tasks difficult.
- the presence of noise jamming in the environment, which adversely affects certain receiver types.
- the presence of high powered 'friendly' radars in the vicinity of the ESM system which can seriously impede certain aspects of system performance.

2.14 Moreover, the structure of the current generation of Automatic ESM systems implies that errors arising at the receiving stages due to these adverse operational conditions are propagated through the de-interleaving and modulation analysis elements. As a direct consequence of this error propagation, the classification function often produces highly ambiguous (i.e. several possible emitter classifications are presented) or in the limit erroneous results.

### 3 KNOWLEDGE BASED ESM SYSTEM DEVELOPMENT

3.1 To directly address the emitter classification problem described in the last section, and with the overall aim of improving ESM system effectiveness, Software Sciences Ltd embarked on a privately-funded Knowledge Based ESM System (KB-ESM) development programme.

3.2 The aims of this development were several fold, namely

- to improve the overall performance of automatic ESM by optimising the processing subsystem
- to apply novel hardware and software architectures to achieve this optimal processing
- to assess the improvement that KBS techniques could offer in the classification of radar emitters,
- to develop a comprehensive ESM System Evaluation facility using a suite of modelling programs.

3.3 During the initial phases of this development, a comprehensive survey of the types of Knowledge Based System (KBS) which could be used in ESM processing was undertaken. As a result of this survey, the Blackboard Architecture was chosen because of its flexibility and suitability to the complex time varying signal analysis problems of ESM. The Blackboard Architecture was originally developed for use in speech understanding and has subsequently been used for a variety of applications including Sonar Classification and Sensor Data Fusion.

### 3.4 There are three components of the Blackboard Architecture:-

- the Blackboard
- knowledge sources, and
- the scheduler

The Blackboard is a structured global data base which may be subdivided into levels, panels and entries as shown in figure 2a appropriate to the particular application. The levels usually represent 'levels of abstraction', where the lowest level represents, for example, raw data gathered from a transducer or sensor and the highest levels represent high confidence information deduced from the lower levels. Several different types of entry may exist at each level.

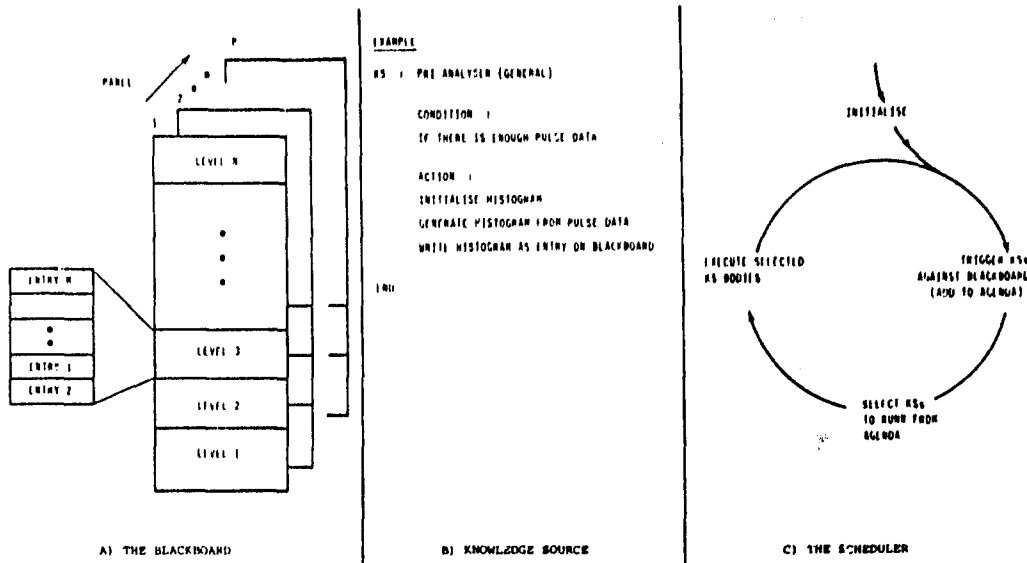


FIGURE 2 BLACKBOARD ELEMENTS

3.5 The Knowledge Sources manipulate, create or consume entries on the Blackboard based upon procedures (algorithmic) or declarative (rule-based) knowledge. An example knowledge source (KS) is shown in Figure 2b. Each KS has a condition part and an action. If the condition part (which refers to entries on the Blackboard) evaluates to be true, then the KS becomes a candidate for activation and as such is placed on an Agenda. If it is activated, its action part will run causing modification to the Blackboard contents.

3.6 The selection of a KS from the Agenda to run is performed by the scheduler, the action of which is shown in Figure 2c. The way in which the scheduler selects the KS from the Agenda on any particular cycle of operation is totally adaptive and in general would also depend on the contents of the blackboard.

3.7 The main features offered by a Blackboard approach as applied to ESM processing are:

- the support of the hypothesis and Test paradigm, whereby initial emitter classification hypotheses are formed and subsequently validated or disproven by the application of special purpose analysis techniques to the pulse chain data.
- the capability to alter the processing priorities adopted within the system according to the current situation, in contrast to the rigid priorities imposed by the more conventional system.
- the ability to allow the system to choose one of several pulse chain analysis algorithms according to the circumstances, for example, special purpose modulation analysis techniques are used to make use of 'a-priori' information of previously detected emitter types or as part of the hypothesis testing process.

3.8 To make full use of these features, a Knowledge Based ESM system model was developed to prove the functionality of the Blackboard approach and to gather performance metrics for use in optimisation of the KB-ESM system towards real time operational usage. The KB-ESM system model incorporates all necessary features of the ESM processing system, including:

- A de-interleaver which is under the full control of the Blackboard mechanisms.
- RF, PRI and PW modulation analysis algorithms.
- Emitter Classification algorithms (including library access and hypothesis and test)
- Special purpose display formats
- Adaptive system control and scheduling

3.9 The KB-ESM system model runs on a VAX 11 series computer under a Knowledge Based System development environment called POPLOG. The development and subsequent assessment carried out to date has shown that within a controlled evaluation environment, the KB-ESM system model is able to produce consistent unambiguous emitter classification results.

3.10 Much of the improved classification capability is due to the application of the hypothesis and test technique. The emitter hypotheses are formed by accessing the emitter library with coarse but reliable pulse chain parameters in much the same way as current generation systems. Each candidate emitter is then subjected to a verification process using distinguishing features of the emitter retrieved from the library record. This information is used as the basis for the 'a-priori' analysis of the pulse chain in question to prove or disprove the existence of the candidate emitter. Only emitter classifications validated in this way are presented to the operator as correct classifications hence decreasing the probability of erroneous or ambiguous results. This process is illustrated in Figure 3.

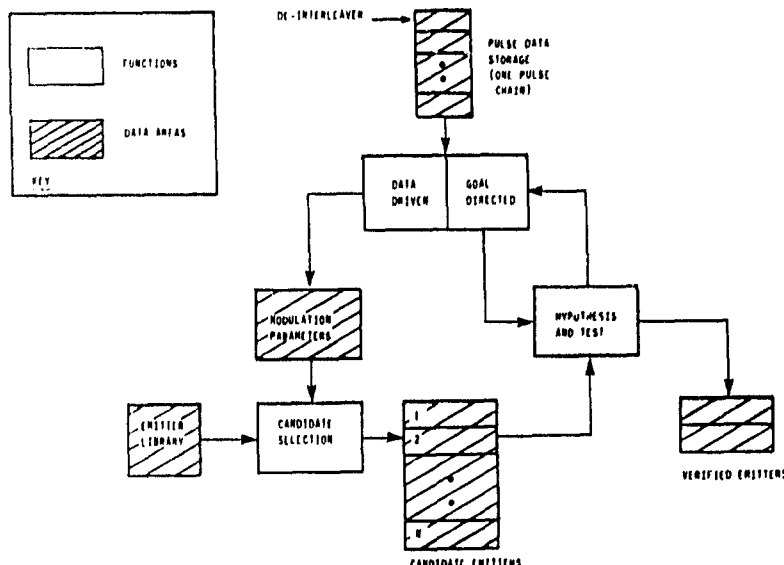


FIGURE 3 HYPOTHESIS AND TEST TECHNIQUE

3.11 In addition to providing reliable classification of a correctly de-interleaved pulse chain, the evaluation of the KB-ESM system model has proven its capability to classify several separate emitters which are initially placed into a single pulse chain due to their close parametric proximity. Furthermore, the KB-ESM system model can successfully recombine split pulse chains from a wide band frequency hopping radar by extending the hypothesis and test technique back to a second (rule-based) de-interleaving stage.

The KB-ESM System model was developed with a set of displays to allow the operator to

- oversee the system operation, using the tabular emitter summary displays common in automatic ESM.
- monitor the hypothesis and test function from candidate emitter set generation through emitter verification using special purpose display formats.
- monitor the modulation analysis of a particular pulse chain using special purpose graphical display options.

The strictly hierarchic nature of these displays ensures that the system defaults to fully automatic mode, with summary displays available for this purpose. However, the 'lower level' display options can be invoked to allow the skilled operator to monitor the detailed system operation.

#### 4 KB-ESM SYSTEM EVALUATION

4.1 In order to assess fully the capabilities and limitations of the KB-ESM System Model, a comprehensive evaluation programme was undertaken following system development. Since an incremental and controlled assessment technique was essential to this evaluation programme, a modelling approach was adopted throughout. This will be followed in the near future by the development and assessment of a prototype trials system.

4.2 A block diagram of the assessment facility used to evaluate the KB-ESM system model is presented in Figure 4. The evaluation process consisted of the generation of test scenarios of various complexities from which the signal environment at the ESM receiver could be simulated. The performance of the ESM receiving element was subsequently modelled and the receiver output used to evaluate the KB-ESM.

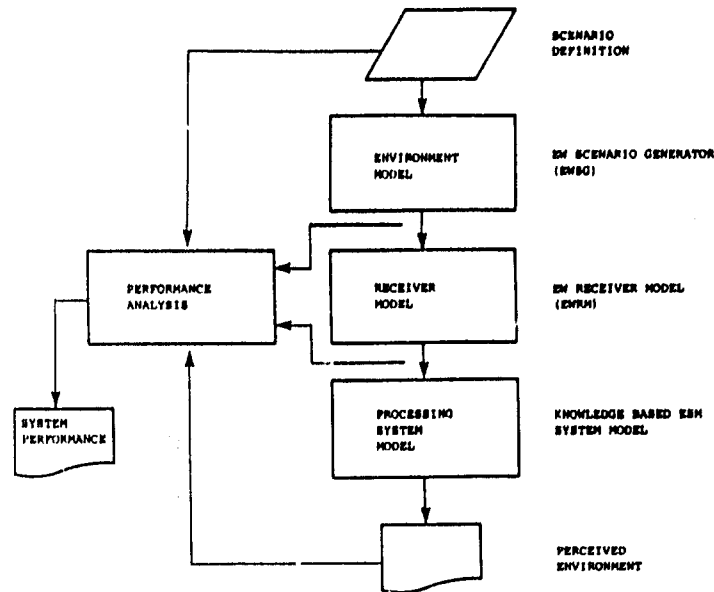


Figure 4 EVALUATION SYSTEM

4.3 The Environmental Modelling function was accomplished using the Software Sciences EW Scenario Generator (ESWG) program. ESWG allowed the operational Scenario to be defined in terms of the relevant platforms (airborne, shipborne or landbased), their position and their radar fits. The characteristics of the radar fits were subsequently used to generate an electromagnetic environment (i.e. pulsed, CW and jamming signals) as incident at a user specified sensor position. The operational scenario was dynamic in that full platform motion was modelled throughout the simulation including platform manoeuvres in course, speed, altitude, roll, pitch and yaw at predefined simulation times. The simulated signals were of a highly sophisticated nature to represent postulated modulation agility schemes and scan strategies.

4.4 The subsequent Receiver Modelling function was accomplished using the Software Sciences EW Receiver Modelling (EWRM) program which allowed the user to model either

- Channelised Receiver,
- an Instantaneous Frequency Measurement Receiver,
- a Swept Superhet Receiver or
- a Multiport Bearing receiver

The antenna system was fully defined in terms of:

- its polar diagram in the Azimuth and Elevation planes
- the variation of this polar diagram with RF

4.5 Furthermore, suitable interpolation routines were provided to calculate the antenna gain in a general (i.e. non planar) direction and at any pulse frequency.

4.6 Similarly, the Direction Finding and RF receiver element characteristics such as:

- Sensitivity (as a function of RF)
- Dynamic Range
- Bandwidth
- Dead time (due to recovery effects)
- Simultaneous Signal Capability
- ECM resistance

were simulated, as were the principle sources of parameter measurement error within the particular receiver type. The output of the receiver model was subsequently used in the controlled evaluation of the KB-ESM.

4.7 Since the assessment of the KB-ESM system model was accomplished in controlled conditions generated by an environmental model, it was possible to assess automatically the performance of the receiving and processing subsystems. This was possible since pulse data generated by the Environment Model was 'tagged' with a source emitter identification field. This field was compared with the ESM system's perception of the emitter type to give an assessment of system performance.

## 9 CONCLUSIONS

5.1 The development and subsequent thorough evaluation of the Knowledge Based ESM system model has proven that the application of the Blackboard Architecture and particularly the hypothesis and test method can produce unambiguous emitter classification results. Further, evaluation in scenarios depicting adverse operational conditions for ESM has shown that the techniques are particularly useful in these situations.

5.2 To summarise, the application of the novel software architecture has optimised the effectiveness of automatic ESM and hence the overall aims of the development programme were attained.

5.3 The KB-ESM research programme continues, however, aimed primarily at producing an operational ESM system using the techniques described in this paper. The other main areas of research activity are

- the extension of the Blackboard Architecture to control the ESM receiver and hence produce optimal receiver response to augment the emitter classification process.
- the extension of the KB-ESM system model to incorporate emitter association and platform classification at the ESM system as part of the hypothesis and test process.
- the use of special purpose display formats and interfaces to allow operator interaction with the KB-ESM system.

These extensions to the KB-ESM system will further improve the effectiveness of automatic ESM by optimisation of the processing elements.



## DISCUSSION

K. Voles, UK

What, roughly, is the typical scale ratio between the rate at which the modelling is performed and real-time?

B. Jackson

Currently the KB-ESM system is written in POP-11 which is run on a timeshared VAX 11-750. When a typical complex EW scenario is simulated the system has been found to run at a rate which is approximately 1000 times slower than real-time. Performance measurements have shown that over 90% of this time is spent in the embedded de-interleaver. This would normally be implemented on a separate high-performance dedicated chip.

Evaluation has shown that the techniques developed are capable of real-time implementation and Software Sciences' current work is in the enhancement of the real-time applicability of the techniques developed. We see this as the adoption of the beneficial aspects of the KB-ESM but implementation in Ada. The Ada implementation will encode the rules as interpreted data structures so as to maintain some of the flexibility of the knowledge based approach.

J. Whalley, UK

Could you briefly describe the POP-11 environment and the problems you have experienced.

B. Jackson

The POP-11 environment used is the POPLOG system originally developed by Sussex University. This runs on a VAX 11-750 under the VMS operating system. This language has been found to be very good at fast prototyping of knowledge based applications in the ESM domain. The limitations encountered have been in terms of speed of execution, overall machine resources consumed, effect on other users of the time shared system and more significantly the program size limitations encountered. The KB-ESM system has grown in complexity during its development phase and has now reached the physical limitations imposed by the POP-11 system. Some further enhancement would be possible if we restructured the existing program to make more efficient use of the available system facilities. It is felt that this would only provide a short term breathing space.

R.W. MacPherson, Canada

Could you comment on the applicability of your techniques to the identification of emitters other than radar?

B. Jackson

The techniques developed have been specifically aimed at the problems encountered in conventional ESM systems. The techniques and approach adopted are directly applicable to other Signal Analysis problems. Software Sciences have already investigated applicability of this approach to the SONAR problem and we believe that the techniques are also applicable to other similar areas. The techniques of emitter association and platform classification developed recently as part of the KB-ESM, but not covered in this paper, are also more widely applicable in the area of multi-sensor data fusion.

R.S. Dale, UK

How does the system react to emitters which are not in the emitter library?

B. Jackson

When an emitter is encountered that cannot be matched against any existing library entry the system is unable to generate a verified hypothesis concerning the identity of the emitter. As such the system states that it is unable to reach verified status and tells the operator that it has detected a previously unknown emitter. This is an improvement on existing systems which frequently inform the operator of an incorrect identification when an exact match cannot be made. The KB-ESM system having concluded that the detected emitter is previously unknown can provide facilities to enable the operator to create an "invalidated" library entry. This entry records the detected parameters of the new emitter and can provide various recording facilities to enable further analysis on return from the current mission.

H. Timmers, Netherlands

How are the input data generated? Are they assembled from real life, or are they generated artificially?

How do you deal with uncertainty in the data?

B. Jackson

The input data has been generated using two of Software Sciences' EW simulation and modelling packages EWSG & EWRM. EWSG is a general purpose Radar environment scenario generator that is capable of producing digitally encoded pulse data for up to 99,999 different emitters each of which can be fully defined in terms of electromagnetic radiation properties and positional movement. EWRM is a package which enables the realistic modelling of all common ESM receiver types with the ability to fully specify the receiver characteristics using a high level interpretive English like language. The scenarios modelled using these facilities were defined and agreed in conjunction with the UK MoD, RAF and RSRE to be truly representative of certain predicted threat situations. The KB-ESM system deals with uncertainty in the data by the use of the knowledge based techniques described in the paper. The extensive evaluation exercise that was undertaken was centred around predefined situations which cause uncertain and ambiguous classification in the current generation of ESM systems. The KB-ESM system was proven to be significantly better than existing systems at deriving unambiguous and correct interpretation of small quantities of "uncertain data".

